

IDENTIFICATION OF A COMPOUND SPINEL AND SILICATE PRESOLAR GRAIN IN A CHONDRITIC INTERPLANETARY DUST PARTICLE. A.N. Nguyen^{1,2}, K. Nakamura-Messenger^{1,2}, S. Messenger¹, L.P. Keller¹, and W. Klöck³, ¹Robert M. Walker Laboratory for Space Science, ARES, NASA Johnson Space Center, Houston TX 77058, USA, ²Jacobs, NASA Johnson Space Center, Houston TX 77058, USA. ³Helmut Fischer GmbH, Wörishofener Straße 37, Stuttgart, 70372, Germany. (lan-anh.n.nguyen@nasa.gov)

Introduction: Anhydrous chondritic porous interplanetary dust particles (CP IDPs) have undergone minimal parent body alteration and contain an assemblage of highly primitive materials, including molecular cloud material, presolar grains, and material that formed in the early solar nebula [1-3]. The exact parent bodies of individual IDPs are not known, but IDPs that have extremely high abundances of presolar silicates (up to 1.5%) most likely have cometary origins [1, 4]. The presolar grain abundance among these minimally altered CP IDPs varies widely. “Isotopically primitive” IDPs distinguished by anomalous bulk N isotopic compositions, numerous ¹⁵N-rich hotspots, and some C isotopic anomalies have higher average abundances of presolar grains (~375 ppm) than IDPs with isotopically normal bulk N (<10 ppm) [5]. Some D and N isotopic anomalies have been linked to carbonaceous matter, though this material is only rarely isotopically anomalous in C [1, 5, 6]. Previous studies of the bulk chemistry and, in some samples, the mineralogy of select anhydrous CP IDPs indicate a link between high C abundance and pyroxene-dominated mineralogy [7]. In this study, we conduct coordinated mineralogical and isotopic analyses of samples that were analyzed by [7] to characterize isotopically anomalous materials and to establish possible correlations with C abundance.

Samples and Methods: The IDP selected for this study, W7027E6, is ~12 µm in size. Bulk chemical analyses were previously conducted by scanning electron microscopy/EDX and showed a bulk C content of 11.7 wt% [7]. Following the SEM examination, the sample was embedded in epoxy and sectioned by ultramicrotomy into 70 nm thick slices which were deposited onto Cu TEM grids. We examined the mineralogy and chemical compositions of these microtome sections by transmission electron microscopy (TEM). Bright-field images and quantitative X-ray maps were acquired for all sections using the JSC JEOL 2000FX TEM and 2500SE STEM.

Following these analyses, the sample was reinforced for isotopic measurement by coating the backside of the TEM grid C-support film with Au. Due to the delicate nature of the sample however, some of the slices were damaged during this process. Three of the IDP sections were analyzed for O and N isotopes by raster ion imaging in the JSC NanoSIMS 50L. Images of ¹⁶O⁻, ¹⁷O⁻, ¹⁸O⁻, ¹²C¹⁴N⁻, ¹²C¹⁵N⁻, ²⁸Si⁻ and

²⁴Mg¹⁶O⁻ were simultaneously acquired with electron multipliers. For each IDP section, a ~1 pA, 100 nm Cs⁺ primary ion beam was rastered over 5.5 – 8 µm fields of view for 35 layers. San Carlos olivine and 1-hydroxy benzotriazole hydrate were used for tuning and as external standards for O and N, respectively. Three thin sections have been analyzed by both TEM and NanoSIMS.

Results: TEM observations: W2027E6 is a typical anhydrous IDP dominated by very porous fine grained aggregates embedded in carbonaceous material. No magnetite rims on mineral grains were observed, suggesting minimal atmospheric entry heating. W2027E6 contains a large Fe,Ni-sulfide cluster in the center (1.5 µm), abundant GEMS (glass with embedded metal and sulfides) grains, and 20-500 nm sized enstatite, diopside, and sulfide grains. There are no obvious nanoglobules among the carbonaceous material. There is a 345×260 nm sized grain composed of an Al-rich core surrounded by Si-rich material (Fig. 1). The Al-rich region has the chemical composition of spinel (MgAl₂O₄) with trace amounts of Ti and Fe and is crystalline. The material surrounding the spinel is a glassy, non-stoichiometric Mg- and Si-rich silicate. In one portion of the glass, Fe occurs in inclusions, whereas it is distributed more uniformly in the other portion. An enstatite whisker (1400×300 nm) and a small enstatite platelet (500×50 nm) are also observed.

NanoSIMS: The enstatite whisker has normal O isotopic composition relative to terrestrial ($\delta^{17}\text{O} = 14 \pm 15\text{‰}$, $\delta^{18}\text{O} = 7 \pm 7\text{‰}$). We observed 11 ¹⁵N-rich regions with $\delta^{15}\text{N}$ up to 740 ‰ relative to terrestrial in the thin sections. The ¹⁵N-rich areas had sizes ~110-300 nm and are associated with carbonaceous material. Such enrichments are commonly observed in CP IDPs and primitive meteorites and fall within the predictions of chemical reactions in dense molecular clouds [8].

The core-mantle spinel and glass grain has an enrichment in ¹⁷O ($\delta^{17}\text{O} = 925 \pm 70\text{‰}$) and depletion in ¹⁸O ($\delta^{18}\text{O} = -152 \pm 20\text{‰}$) (Fig. 2). This isotopic composition is consistent with an origin in a low-mass red giant star. NanoSIMS isotopic analysis also indicated the central portion of the grain has lower ²⁸Si/¹⁶O⁻ and ²⁴Mg¹⁶O⁻/¹⁶O⁻ ratios than the surrounding silicate material. The estimated presolar silicate abundance among all three sections is ~1060 ppm.

Discussion: The enstatite whisker has an isotopic

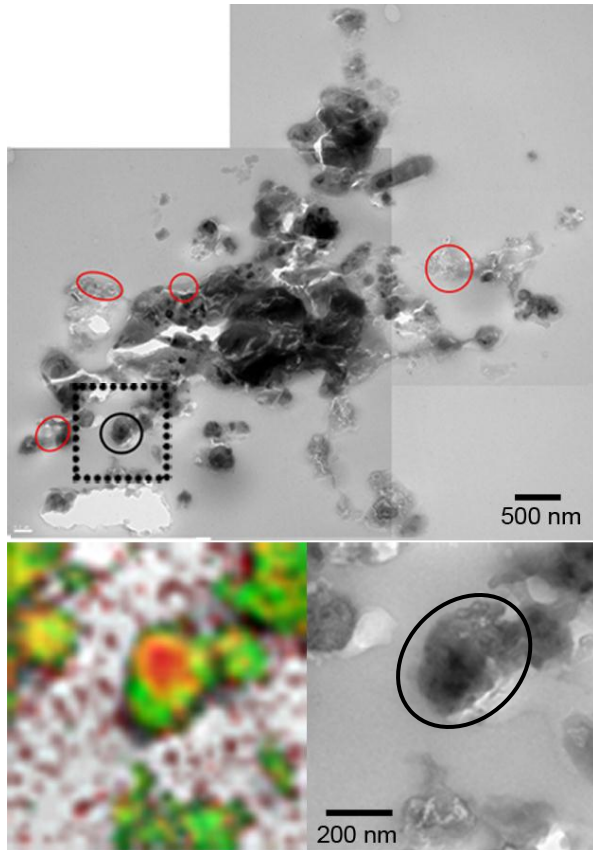


Figure 1: (top) Bright-field TEM image of W7027E6, slice#6. Circled are the presolar spinel and glass grain (black) and ^{15}N hotspots (red). **(bottom)** Si (green) and Al (red) X-ray map and high resolution TEM image of boxed region in the top image.

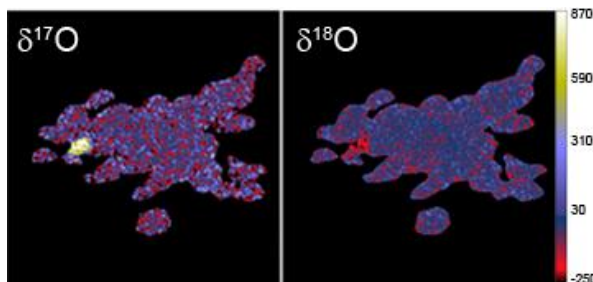


Figure 2: O isotopic ratio images of IDP W7027E6, slice#6 showing an ^{17}O -rich, ^{18}O -depleted spinel and glass core-mantle presolar grain.

composition that is more ^{16}O -poor compared to previous measurements of enstatite whiskers in IDPs [9]. However, it is consistent with the O isotopic compositions of Solar System materials. The unique crystal morphologies and microstructures likely result from condensation above ~ 1300 K in a low-pressure nebular or circumstellar gas [10].

The unique core-mantle presolar grain identified in this study of W7027E6 is the first detection of presolar spinel in an IDP. Until now, only presolar silicate

grains, Al_2O_3 , and SiC have been identified in IDPs [11]. Presolar spinel grains in meteorites have an abundance of ~ 1 ppm, but few have been analyzed by TEM. Recent mineralogical studies of 4 presolar spinel grains reveal three are stoichiometric Al-Mg-rich single crystals that formed under equilibrium conditions, and one is an assemblage of three Fe-Cr-rich crystals that likely formed under non-equilibrium conditions [12]. None of these spinel grains are associated with isotopically anomalous silicate material.

Three presolar grains consisting of silicate and oxide material have previously been reported, though they differ from the grain studied here. One grain is an amorphous silicate with 20 nm inclusions of probable hibonite crystals [13], and two grains have Ca-Al-rich oxide cores surrounded by silicate material [14, 15]. The mineral identifications of the oxide phases in these grains are uncertain. The compound presolar grain reported here is the first occurrence of a single spinel crystal surrounded by a silicate mantle. Equilibrium condensation theory indeed predicts that oxide grains such as TiO_2 or Al_2O_3 could serve as seed nuclei for silicate growth in circumstellar environments, though these nuclei are predicted to be only a few nanometers in size [16]. The presolar spinel in this study likely condensed in the circumstellar envelope under equilibrium conditions below ~ 1500 K. Yet the non-stoichiometric glassy silicate mantle suggests formation below the glass temperature under non-equilibrium conditions. These conditions are consistent with predictions for outflows of O-rich evolved stars in which amorphous non-stoichiometric silicates are the major condensate [16]. The distinct formation conditions of the grain components indicate varying physical and chemical conditions experienced by the grain during condensation in the circumstellar envelope.

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